Influence of object surface roughness in CT dimensional measurements

Amalija Horvatić Novak[1], Biserka Runje[2]

[1] PhD student at Faculty of mechanical engineering and naval arhitecture, Ivana Lucica 5, Croatia, e-mail: amalija.horvatic@fsb.hr

[2] Faculty of mechanical engineering and naval arhitecture, Ivana Lucica 5, Croatia, e-mail: biserka.runje@fsb.hr

Abstract

Computed tomography as a non-contact and non-destructive method is of great interest for use in dimensional measurements. It is a method that enables insight into internal structure of inspected part and measurement of internal geometry, but one big disadvantage of the method is lack of metrological traceability. In order to assess measurement uncertainty and achieve metrological traceability, parameters that influence CT dimensional measurements must be defined and their contribution to overall measurement uncertainty must be assessed. One of the parameters that influence CT measurement is influence of object geometry and characteristic of object surface. In this paper, influence of surface roughness, as the parameter of inspected object, on CT dimensional measurements will be investigated and results will be analyzed.

Keywords: computed tomography, dimensional measurement, surface roughness

1 Introduction to Computed Tomography

Computed tomography (CT) is a method known for over 40 years, but its application in a field of dimensional measurements is relatively new. It is a non-contact, non-destructive measurement method that enables insight into both external and internal geometry of inspected part and allows 3D measurements of characteristics unreachable with other measurement methods. The process can be divided into three sub processes (Figure 1): CT scanning, reconstruction of 3D model and dimensional measurements. In CT scanning process the part is illuminated with X-rays during its rotation for 360° and a big number of 2D scans is collected.

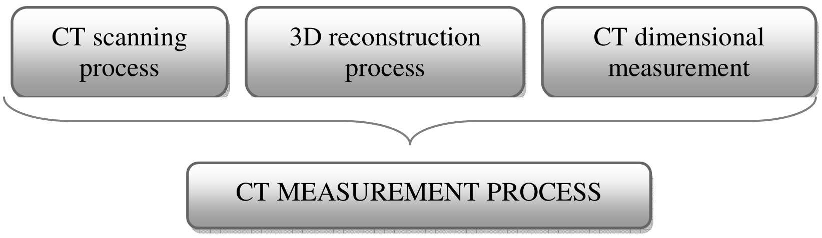


Figure 1: CT measurement process

Each 2D scan stands for one step of inspected parts' angular view. In the second sub process those images are used for 3D reconstructions of inspected part, while in third sub process dimensional measurements are carried out on obtained 3D model. Concerning the fact that it is quite complex measurement method, with huge number of parameters that influence one or more sub processes and impact measurement results, metrological traceability of CT in dimensional metrology is still not achieved [1-4]. In this paper classification of influence parameters will be given and one of the influence parameters, object surface roughness, will be analyzed and explained.

2 Influence parameters

The main problem when using CT for dimensional measurements is lack of measurement uncertainty of obtained results. In order to assess measurement uncertainty, influence parameters in CT systems must be identified and their contribution to overall measurement uncertainty needs to be defined. At this time, many different classifications of influence parameters exist. Parameters can be divided according to sub process in which they appear and influence the process or they can be divided into hardware influencing parameters, software influencing parameters and other parameters. On the other hand, some authors [5-7] classified influencing parameters as: environmental parameters, hardware parameters, software parameters, object related parameters and influence of operator. Here, classification of parameters considers parameters that influence CT scanning process, 3D reconstruction process and process of dimensional measurements and is given in Figure 2.

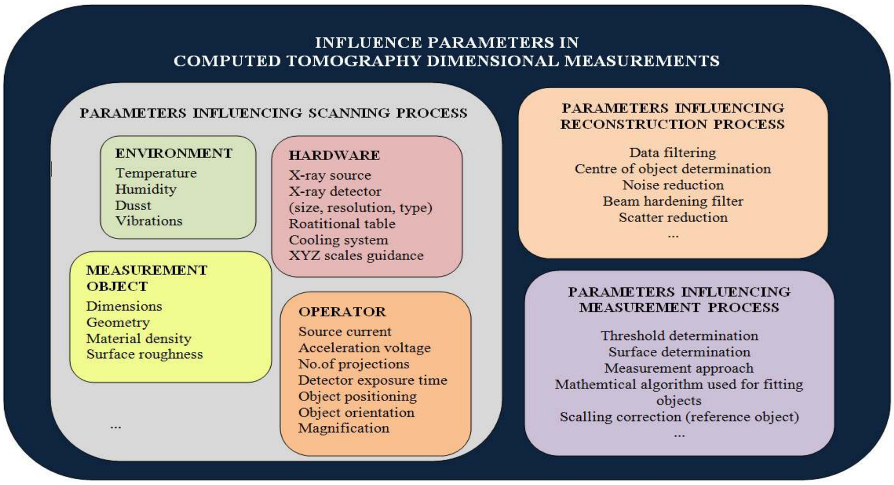


Figure 2: Classification of influence parameters in CT dimensional measurements

Parameters that influence scanning process are further divided to environmental parameters, hardware parameters, parameters of measurement object and parameters chosen by operator. Surface roughness is here classified as parameter related to measurement object which influences first sub process, CT scanning process. Previous researches showed existence of object surface roughness influence on measurement results and

3 Experimental research

The main problem which was investigated in this paper was influence of surface roughness on measurement results obtained with use of computed tomography method. Some previous researches dealt with the same problem and highlighted the need for its further investigation [8, 9]. In order to analyze CT results of cylinders' outer diameters with different surface roughness, reference measurements were conducted. Reference measurements included surface roughness measurements and measurement of cylinders' outer diameter on coordinate measuring machine (CMM). Nominal sizes of aluminium cylinders were the same (Figure 3). Figure 4 presents inspected cylinders.

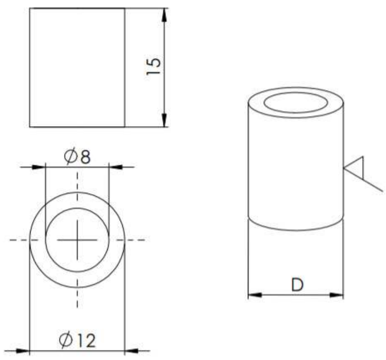


Figure 3: Drawing of inspected cylinders

Figure 4: Inspected cylinders with growing roughness parameters

3.1 Surface roughness measurements

Surface roughness of outer cylinder diameter was measured according to ISO 4288:1996 and observed were amplitude parameters *Ra* (arithmetic mean deviation of the assessed profile) and *Rz* (maximum height of the profile), as well as, spatial parameter *RSm* (mean spacing of profile elements) which is interesting on surfaces having periodic or pseudo-periodic motives, such as turned surfaces [10, 11]. Table 1 presents basic information about mentioned surface roughness parameters, with explanation of each parameter [12, 13].

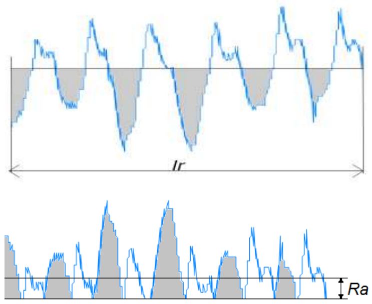
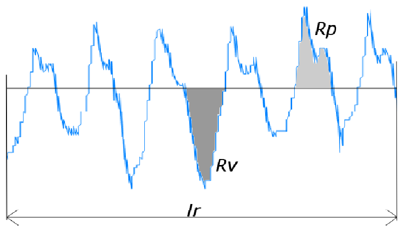
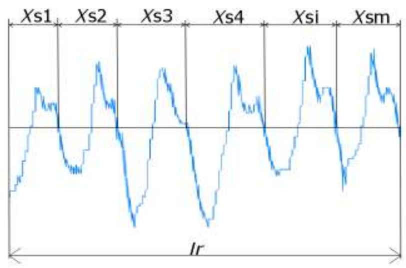
Ra – arithmetic mean surface roughness	*Rz* – surface roughness depth	*RSm* – average groove width
$R_a = \frac{1}{l}\int_0^l \lvert Z(x)\rvert dx$	$R_z = R_p + R_v$	$RSm = \frac{1}{m}\sum_{i=1}^{m} Xs_{\mathrm{i}}$
		

Table 1: *Ra*, *Rz* and *RSm* parameters

Parameter *Ra*, defined as arithmetic mean deviation of the assessed profile, is a commonly used parameter for expression of surface roughness. The benefit of this parameter is fact that it is insensitive on local surface defects, so stable results can be obtained [14]. The negative aspect of parameter is that even totally different surfaces, strongly rough or extremely fine can have the same amount of parameter *Ra* (Figure 5). Moreover, the same *Ra* roughness can be obtained with totally different machining processes.

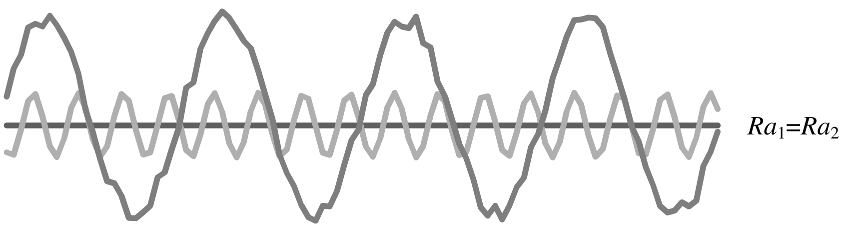


Figure 5: An example of the same amount of *Ra* parameter in two different cases

Other amplitude parameter taken into consideration in this research was parameter *Rz*. *Rz* is defined as maximum height of surface roughness profile and represents the sum of profile peak and profile valley on sampling length *lr* [13, 14]. *Rz* is the most commonly used parameter for expressing the surface roughness. It is parameter that allows checking whether the profile has juts which can affect static or sliding contact function [12]. Both, *Ra* and *Rz* parameters are expressed in micrometers. Considering the fact that observed objects were made by turning, one more parameter was taken into consideration, *RSm*. It is a spatial roughness parameter which expresses the mean of the profile elements width in a sampling length *lr* [14]. *RSm* is used to specify surface roughness of surfaces machined by periodic processing, e.g. turning milling, planing. Unit for expression of *RSm* parameter is a millimetre.

Measurement of surface roughness was conducted with use of Taylor Hobson Surtronic 25 device and TalyProfile Silver software for roughness measurements. Measured results for all four samples are summarized in table 2.

	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4
***Ra*, µm**	0.29	2.05	7.06	19.50
***Rz*, µm**	2.06	10.30	27.80	81.50
***RSm*, mm**	0.049	0.168	0.349	0.556

Table 2: Surface roughness for all four cylinders

Figures 6a to 6d presents roughness profiles for four inspected cylinders. Profiles are obtained in software Taly Silver Pro. All four measurements of roughness are conducted on evaluation length of 4 mm, meaning that chosen cut-off filter was 0.8 mm. In case of fourth cylinder, recommended evaluation length is 12.5 mm, but it was not feasible to apply this because of cylinder length.

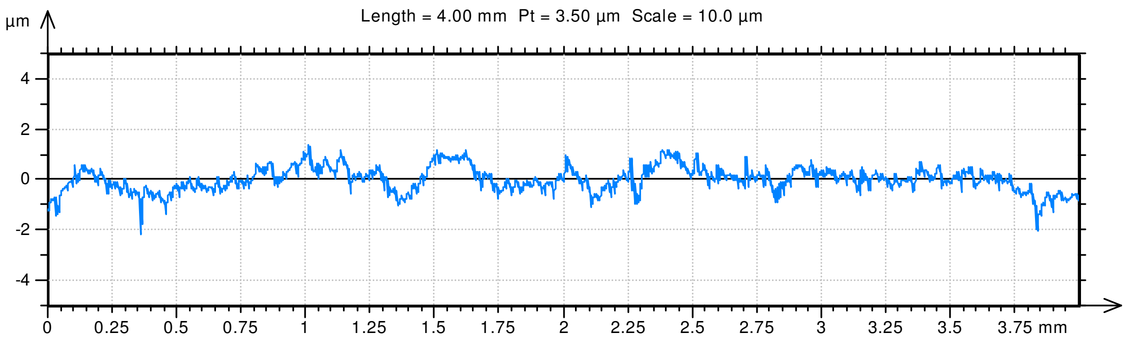


Figure 6a: Roughness profile for Cylinder 1

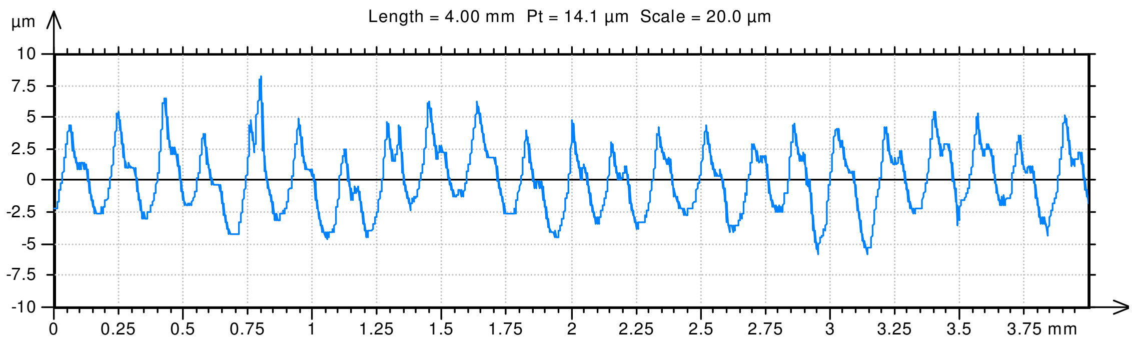


Figure 6b: Roughness profile for Cylinder 2

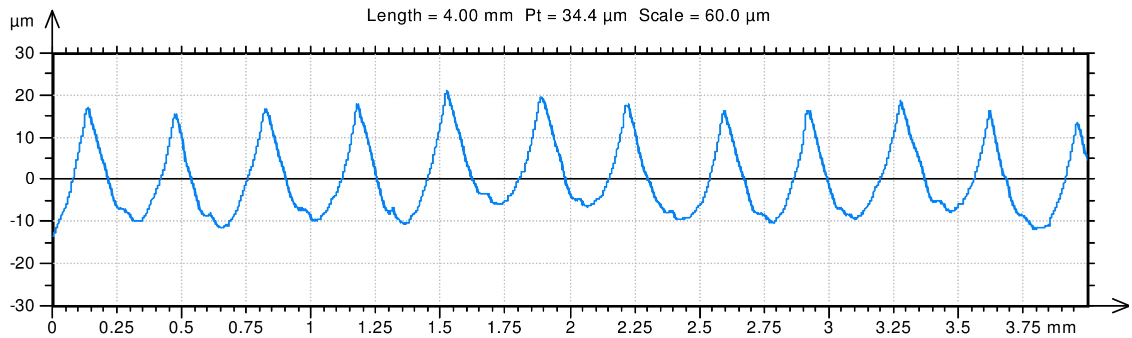


Figure 6c: Roughness profile for Cylinder 3

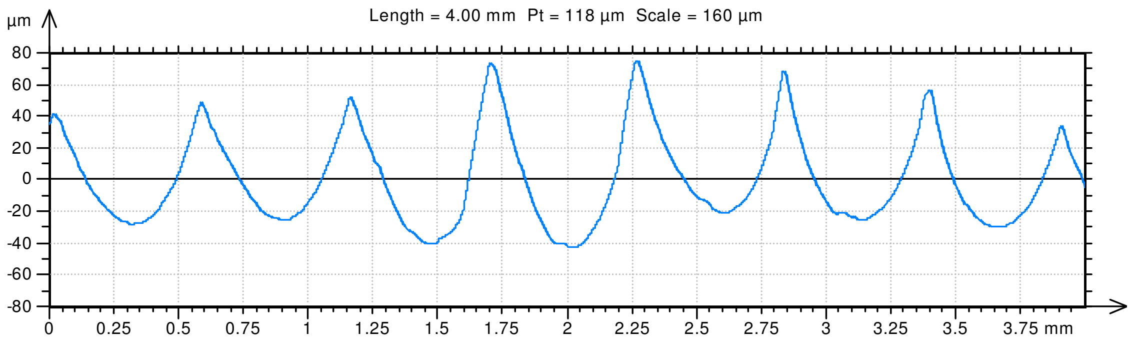


Figure 6d: Roughness profile for Cylinder 4

Cylinders are numbered according to their roughness so cylinder 1 has the lowest surface roughness parameters and cylinder 4 the highest.

3.2 Reference dimensional measurements

Measurements with tactile coordinate measuring machine (CMM) were conducted and those results are assumed to be reference values. Observed dimension was cylinder outer diameter and measurements were performed on coordinate machine Ferranti Merlin with use of software MODUS. Measurements were conducted three times and arithmetical mean of results was set to be reference value of outer diameter. Table 3 presents measured results and related measurement uncertainties.

Sample	**Outer diameter *D*, mm**	**Expanded measurement uncertainty *U*, µm, *k* = 2, *P* = 95 %**
Cylinder 1	11,9349	4
Cylinder 2	11,9649	4
Cylinder 3	11,9699	4
Cylinder 4	12,0747	4

Table 3: Reference values

3.3 CT dimensional measurements

CT scanning was performed on industrial CT device Nikon, XT H 225. The parameters chosen for scanning process are given in Table 4. With the fact that influence of object surface roughness on measurement results were investigated, parameters in CT measurement process were kept constant.

Parameter	**Amount**
Voltage, kV	90
Current, µA	55
No.of projections	1000
Detector size, pixels	3192 x 2296
Pixel size, µm	127 x 127
X-ray spot size, µm	4,95

Table 4: Scanning parameters

CT models of scanned cylinders were generated with use of software package CT-Pro, and measurements were performed in software VGStudio Max 3.0. Inspected were only outer diameters of observed cylinders since they had significant different surface roughness. Chosen measurement strategy involved fitting simple geometry object cylinder where used mathematical model was Gaussian method.

4 Results and discussion

Obtained results from CT measurements are observed as deviations from reference values. In order to minimize influence of other parameters, chosen parameters of CT scanning process for all four aluminium cylinders are kept the same, as well as 3D reconstruction and dimensional measurement approaches. Furthermore, the same measuring approach was used, which included fitting simple shape of cylinder, based on Gaussian method, to volumetric data sets in both cases when measuring cylinders' outer diameter.

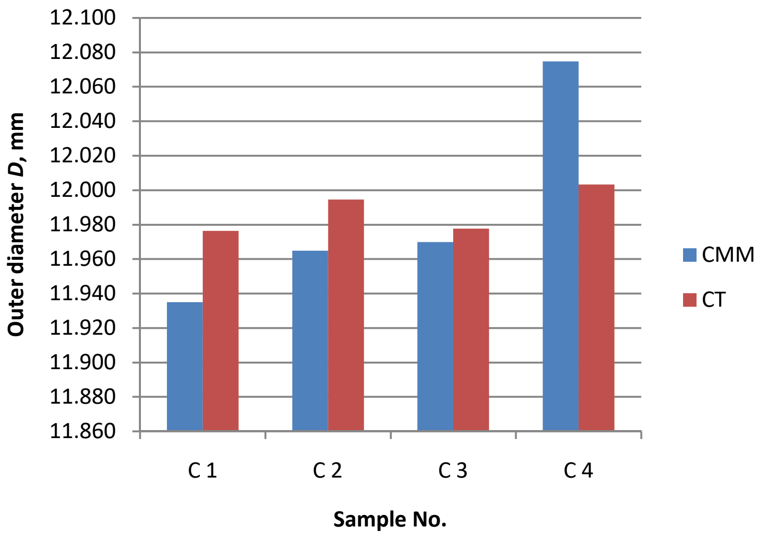
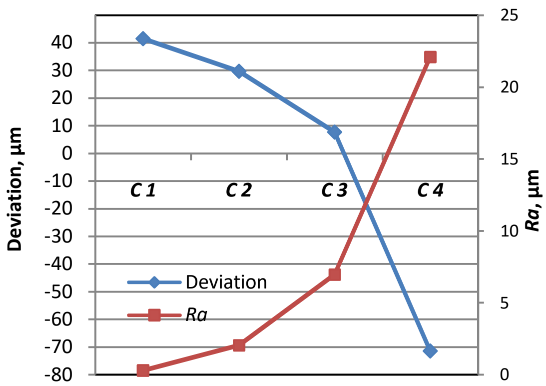
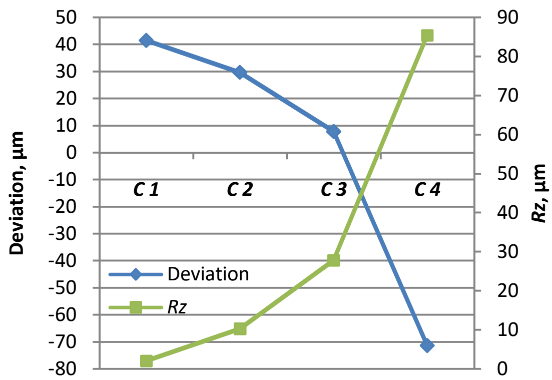


Figure 7: Results of outer diameter from CMM and CT measurements

Figure 7 shows results of outer diameter obtained with both CMM and CT measurements. In first three cases diameters obtained with CT are larger than those obtained with CMM. In fourth case - measurement of the cylinder with greatest roughness among the observed cylinders - results obtained with CT are smaller than those obtained with CMM. Also, in case of measuring third cylinder *C3*, the deviation between obtained results is the lowest and amounts 8 µm.

Next figures show behavior of results in dependence of observed roughness parameters. Figure 8 shows deviation in results in dependence of amplitude roughness parameters, *Ra* and *Rz*. Cylinders are ranked according to their surface roughness parameters where the cylinder 1, marked as *C1*, was fine turned and has the lowest measured roughness, both *Ra* and *Rz*, and opposite cylinder 4, marked as *C4*, was produced by rough turning and has high *Ra* and *Rz* parameters. In both cases, deviation between measured results of CT and CMM measurements behave in the same way. The largest deviations are observed in cases where surface roughness was either low or high. The lowest deviation between results is observed in case of measuring the outer diameter of cylinder *C3* where *Ra* amounts 7.06 µm and *Rz* 27.80 µm.





a) b)

Figure 8: Deviation of outer diameters in dependence on the amplitude roughness parameters: a) *Ra*, b) *Rz*

The same analysis was conducted for *RSm* parameter. The conclusion is the same, the largest deviation in obtained results is observed in case when measuring outer diameter of cylinders 1 and 4.

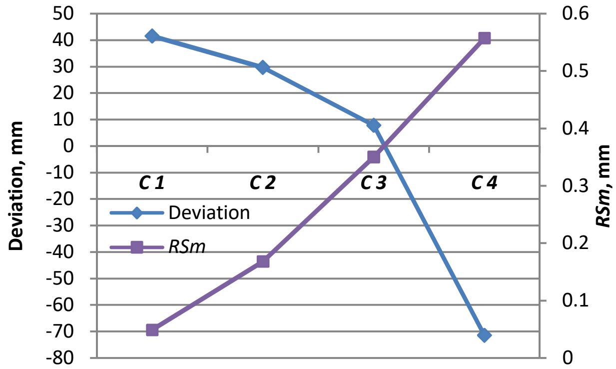


Figure 9: Deviation of outer diameters in dependence on the spatial roughness parameter: *RSm*

Conclusion

In this research influence of surface roughness on measurement results obtained by use of computed tomography method was monitored. Dimensional characteristic of cylinder outer diameter, on four aluminium cylinders with significantly different surface roughness, was measured and observed. Obtained results were observed as deviations from reference values obtained on tactile CMM and the following conclusions were made:

a) Influence of surface roughness parameter on measurement results exists.

b) The biggest deviations in obtained results are perceived both in cases where surface is fine or strongly rough.

Addressing the conclusions made from this experiment, the following steps are proposed: Influence of surface roughness parameters should be further investigated. The recommendation is to investigate behavior of results for cases where surface parameters are in between obtained amounts. The expectations are that behavior of results will have the same trend and if so, surface roughness parameter influence on CT results in that case could be determined.

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